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Stability of Wheat Genotypes by AMMI and Yield Evaluated under Peninsular Zone of India

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ABSTRACT

Background: Efficient estimation of main and interaction effects under multi environment trials had been carried out by AMMI. Studies with low proportion of the variance explained by first interaction principal component IPCA1 under AMMI analysis had been reported biased interpretation for the stability of the genotypes.

Methods: Weighted Average of Absolute scores (WAASB), quantitative stability measure had been recommended for selection of productive genotypes with broad adaptation. The selection of promising genotypes had been assisted by use of superiority index (WAASBY) that considered simultaneous use of yield and stability by allowing variable weighting mechanism for yield and stability.

Result: Wheat GW509 and HI1633 genotypes had been identified by stability measure WAASB for the first year. While Superiority index considered stability and high yield settled for HI1633 and Raj4083 genotypes. Analytic measures of adaptability PRVG and MHPRVG observed suitability of HI1633 and Raj 4083. SI expressed positive linear behaviour with yield, MHPRVG and PRVG measures. While stability measure WAASB maintained moderate negative correlation with yield, SI, MHPRVG and PRVG. Wheat genotypes HI1633, HI1641 and HI1646 identified by stability measure for the next year of study. Superiority index selected HI1641, HI1633 and MACS6752 genotypes. SI expressed direct linear relation with yield, MHPRVG and PRVG. Stability measure exhibited indirect relationships with SI, MHPRVG, PRVG and yield Wheat genotypes HI1633, Raj 4083 for first year and HI1641, MACS6752 for the second year of study.

Key words: AMMI analysis, ASV, SIPC, Za, EV, SI, SSI, Biplot graphs.

INTRODUCTION

AMMI model has been mostly employed to separate the additive variance from the multiplicative of the interaction portion by the use of principal component analysis (PCA) (Gauch, 2013; Bocianowski *et al.,* 2019). This analytic mechanism captured the large portion of the G×E interaction sum of squares (Zhang *et al.,* 1998; Ajay *et al.,* 2019). Analysis of Multi Environment trials, irrespective of crops, demand an efficient estimation of main and interaction effects (Bornhofen *et al.,* 2017). More over biased interpretation regarding the stability of the genotypes had been also reported when low proportion of the variance explained by first interaction principal component IPCA1 under AMMI analysis (Ramburan *et al.,* 2011; Zali *et al.,* 2012; Oyekunle *et al.,* 2017). The quantitative stability measure *i.e.* Weighted Average of Absolute scores (WAASB), as an important statistical tool recommended for identifying productive genotypes with broad adaptation (Olivoto, 2018). The most stable genotype possessed the lower value of WAASB measure *i.e.* deviates minimum from the mean performance across environments (Olivoto, 2019). The selection of promising genotypes had been assisted by use of superiority index (WAASBY) that is the simultaneous use of yield and stability by variable weighting mechanism for yield and stability of genotypes (Olivoto *et al.,* 2019). The prime objective of the present study was to validate the type of relationships between WAASBY and other stability measures, as per AMMI model, of wheat genotypes evaluated under multi environmental trials in the Peninsular Zone of the India under irrigated late sown trials in the recent past.

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MATERIALS AND METHODS

Mainly Maharashtra and Karnataka states represents the Peninsular zone of our country. All three species of wheat *viz* T. *aestivum, T. durum* and T. *dicoccum* are cultivated in this zone. Bread wheat cultivation is concentrated under irrigated environments, whereas, the cultivation of durum and dicoccum wheat is generally confined to rainfed/ restricted irrigation situation. Seven released wheat genotypes evaluated at twelve locations and eleven genotypes at thirteen locations were evaluated under field trials during 2018-19 and 2019-20 cropping seasons respectively. Field trials were conducted at research centers in randomized complete block designs with three replications. Recommended agronomic practices were

followed to harvest good yield. Details of genotype parentage along with environmental conditions were reflected in Tables 1 and 7 for ready reference. Stability measure Weighted Average of Absolute Scores has been calculated as

$$WAASB = \sum_{k=1}^{p} |IPCA_{ik} \times EP_k| / \sum_{k=1}^{p} EP_k$$

Where:

$WAASB_i$= Weighted average of absolute scores of the ith genotype (or environment);

$IPCA_{ik}$= Score of the ith genotype (or environment) in the kth IPCA.

EP_k= amount of the variance explained by the kth IPCA.

Superiority index allows weighting between yield and stability measure (WAASB) to select genotypes that combine high performance and stability as ;

$$SI = \frac{(rG_i \times \theta y) + (rW_i \times \theta s)}{(\theta y \times \theta s)}$$

Where:

rG_i and rW_i= Rescaled values for yield and WAASB, respectively, for the ith genotype.

G_i and W_i= Yield and the WAASB values for i^{th} genotype.

SI= Superiority index for the ith genotype that weights between yield and stability and θY and θS are the weights for yield and stability assumed to be of order 65 and 35 respectively in this study.

AMMI analysis was performed using AMMISOFT version 1.0, available at https://scs.cals.cornell.edu/people/ hugh-gauch/ and SAS software version 9.3. Stability measures had been compared with recent analytic measures of adaptability calculated as the relative performance of genetic values (PRVG) and harmonic mean based measure of the relative performance of the genotypic values (MHPRVG) for the simultaneous analysis of stability, adaptability and yield (Resende and Durate, 2007).

RESULTS AND DISCUSSION

First year of study (2018-19)

AMMI analysis of genotypes

Highly significant effects of environment (E), GxE interaction and genotypes (G) had been observed by AMMI analysis. Environment explained about significantly 55.8% of the total sum of squares due to treatments indicating that diverse environments caused most of the variations in genotypes yield (Table 2). Significant proportion of G×E interaction deserves the stability estimation of genotypes over

Zobel, 1988	Averages of the squared eigenvector values	$EV = \sum_{n=1}^{N} \lambda_{in}^2 / n$
Sneller *et al.,* 1997	Sums of the absolute value of the IPC scores	$SIPC = \sum_{n=1}^{N} \lambda_n^{0.5} \gamma_{in}$
Purchase *et al.,* 2000	AMMI stability Value	$ASV = [(\frac{SSIPC\ 1}{SSIPC\ 2} PCI)^2 + (PC2)^2]^{½}$
Rao and Prabhakaran, 2005	AMMI based stability parameter	$ASTAB = \sum_{n=1}^{n} \lambda_n \gamma_{ni}^2$
Zali *et al*., 2012	ASV1	$ASV1 = [\frac{SSIPC\ 2}{SSIPC\ 1} (PCI)^2 + (PC2)^2]^{½}$
Zali *et al*., 2012	Modified AMMI stability Value	$MASV = \sqrt{\sum_{n=1}^{n-1} \frac{SSIPC_n}{SSIPC_{n+1}} (PC_n)^2 + (PC_{n+1})^2}$
Zali *et al.,* 2012	Absolute value of the relative contribution of IPCs to the interaction	$Z_a = \sum_{n=1}^{N} \lvert \lambda_n \gamma_{in} \rvert$
Ajay *et al.,* 2019	MASV1	$MASV1 = \sqrt{\sum_{n=1}^{n-1} (\frac{SSIPC_n}{SSIPC_{n+1}} PC_n)^2 + (PC_{n+1})^2}$
Resende and Durate, 2007	Relative performance of genotypic values across environments	$PRVG_{ij} = VG_{ij} / VG_i$
Resende and Durate, 2007	Harmonic mean of Relative performance of genotypic values	$MHPRVG_{i.} =$ Number of environments / $\sum_{j=1}^{k} \frac{1}{PRVG_{ij}}$
Olivato *et al.* 2019	Superiority Index	$SI = \frac{(rG_i \times \theta y) + (rW_i \times \theta s)}{\theta y \times \theta s}$

environments (Veenstra *et al.,* 2019). Genotypes explained only 2.8% of total sum of squares, whereas G×E interaction accounted for 17.6% of treatment variations in yield. More of G×E interaction sum of squares as compared to genotypes indicated the presence of genotypic differences across environments and complex G×E interaction for wheat yield. Further partitioning of G×E interaction through the AMMI model revealed that the first five multiplicative terms (IPCA1, IPCA2, IPCA3, IPCA4 and IPCA5) explained 48.8%, 21.5%, 16.4%, 8.3% and 3.9% of interaction sum of squares, respectively. Total of significant components were 99% and remaining 1.0% is the residual or noise, which is not interpretable and thus discarded (Adjebeng *et al.,* 2017).

Stability analysis

Least value of absolute IPCA1 expressed by G2, G1, G6 and higher value achieved by G5 (Table 3). Low values of (EV) associated with stable genotype accordingly, the genotype G6 followed by G7 G3 and genotype G5 had the maximum value of EV measure. The lower value SIPC measure identified G6 followed by G2 as the most stable genotypes, whereas G5 would be of least stable behaviour. Za measure considered absolute value of the relative contribution of IPCs to the interaction revealed G6 and G2 genotypes as most stable in descending order of stability, whereas G5 genotype with the least stability. ASTAB measure observed genotypes G6 and G1 as most stable

Table 1: Parentage details of genotypes and environmental conditions (2018-19).

Code	Genotype	Parentage	Environments	Latitude	Longitude	Altitude
G 1	HI 8807	(HI 8695/ HI 8663// HI 8663)	Niphad	20°4′N	74°6′E	551 m
G 2	HI 1633	GW-322 / PBW-498)	Pune	18°31′N	73°51′E	562 m
G 3	UAS 3002	(RAJ4083/DWR195//HI 977)	Parbhani	19°15′N	76°46′E	413 m
G 4	Raj 4083	(PBW 343/UP 2442//WR 258/UP 2425)	Nasik	19°59′N	73°47′E	583 m
G 5	HD 2932	(KAUZ/STAR//HD2643)	Karad	17°17′N	74°10′E	577 m
G 6	GW 509	(GW 388/MP 4010)	Kolhapur	16°41′N	74°14′E	578 m
G 7	HD 3090	(SFW/VAISHALI//UP2425)	Dharwad	15°27′N	75°0′E	724 m
			Arbhavi	15°84′N	74°51′E	625 m
			Kalloli	16°26′N	74°86′E	625 m
			Nippani	16°23′N	74°22′E	606 m
			Ugar-Khurd	16°39′N	74°49′E	548 m
			Mandya	12°52′N	76°89′E	

Table 2: AMMI analysis of wheat genotypes evaluated under MET (2018-19).

Source	Degree of freedom	Mean sum of squares	Proportional contribution of factors	G×E interaction sum of squares (%)	Cumulative sum of squares (%) by IPCA's
Treatments	83	222.91	76.27		
Genotype (G)	6	111.23	2.75		
Environment (E)	11	1232.38	55.88		
G×E interaction	66	64.81	17.63		
IPC1	16	130.66		48.87	48.87
IPC2	14	65.56		21.46	70.33
IPC3	12	58.70		16.47	86.79
IPC4	10	35.46		8.29	95.08
IPC5	8	21.00		3.93	99.01
Residual	6	7.07			
Error	252	22.84			
Total	335	72.41			

Table 3: Measures of stability as per AMMI analysis of wheat genotypes (2018-19).

Genotype	IPCA1	MASV1	MASV	ASV1	ASV	Za	EV	SIPC	ASTAB	WAASB	SI	MHPRVG	PRVG	Yield
G1	0.65	5.32	4.25	1.97	1.73	20.32	0.082	6.13	38.10	1.061	26.29	0.970	0.974	41.96
G2	0.42	4.74	4.09	1.41	1.27	17.49	0.081	5.23	39.15	0.911	93.16	1.067	1.071	45.95
G3	1.66	7.91	5.85	4.25	3.49	27.61	0.080	6.69	67.36	1.592	12.16	0.980	0.988	41.97
G4	2.15	7.19	5.37	4.58	3.33	27.55	0.082	6.70	62.52	1.599	43.33	1.011	1.020	43.96
G5	3.11	7.60	5.72	6.44	4.55	32.12	0.086	6.95	92.96	1.955	10.87	0.975	0.990	42.51
G6	0.66	2.98	2.28	1.64	1.33	11.70	0.018	3.08	11.50	0.658	35.00	0.973	0.975	41.82
G7	2.18	6.84	5.08	4.66	3.40	27.24	0.072	6.58	58.92	1.589	16.58	0.972	0.983	42.25

Table 4: Simultaneous ranks of wheat genotypes as per yield and AMMI based measures (2018-19).

Genotype	IPCA1	MASV1	MASV	ASV1	ASV	Za	EV	SIPC	ASTAB	WAASB	SI	MHPRVG	PRVG	Yield
HI 8807	8	9	9	9	9	9	12	9	8	3	4	7	7	6
HI 1633	2	3	3	2	2	3	5	3	4	2	1	1	1	1
UAS 3002	9	12	12	9	11	11	8	10	11	5	6	3	4	5
Raj 4083	7	7	7	7	6	7	7	8	7	6	2	2	2	2
HD 2932	10	9	9	10	10	10	10	10	10	7	7	4	3	3
GW 509	10	8	8	9	9	8	8	8	8	1	3	5	6	7
HD 3090	10	8	8	10	9	8	6	8	8	4	5	6	5	4

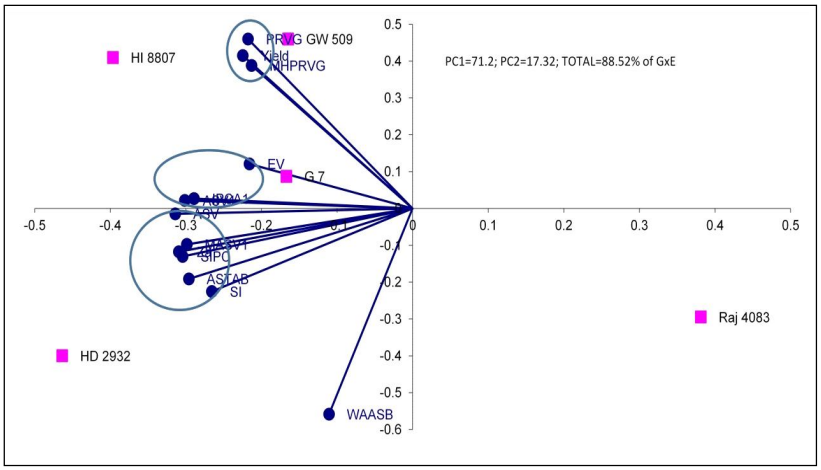

Fig 1: Biplot graphical analysis of stability measures for wheat genotypes evaluated under MET (2018-19).

Table 5: Loadings of stability measures as per first two PC's (2018-19).

Measure	PC1	PC2
IPCA1	-0.289	0.027
MASV1	-0.299	-0.097
MASV	-0.299	-0.097
ASV1	-0.301	0.022
ASV	-0.314	-0.014
Za	-0.309	-0.117
EV	-0.216	0.121
SIPC	-0.304	-0.130
ASTAB	-0.296	-0.191
WAASB	-0.111	-0.559
SI	-0.266	-0.225
MHPRVG	-0.213	0.388
PRVG	-0.218	0.460
Yield	-0.225	0.415
% variance	71.20	17.32

and genotype G5 was least stable in this study (Rao and Prabhakaran, 2005). ASV measure showed that genotypes G2, G3 possessed lower values would express stable performance and G5 be of least stable type. Values of ASV1 selected G2 G6 for their stable behaviour whereas G5 would express unstable performance. Measures MASV and MASV1 consider all significant IPCAs. Values of MASV and MASV1 measure settled for G6 and G2 wheat genotypes. (Ajay *et al.,* 2019). The lower values of WAASB associated with stable nature of genotypes as G6, G2 for considered locations of the zone at the same time maximum value obtained by G5, that is, the one that deviates maximum from the average performance across environments. Superiority index had observed lower values for G5 and G3 whereas large value by G2. Genotypes G7 and G6 were identified for their more stable yield performance by MHPRVG while PRVG measure selected G1 and G7. Maximum yield expressed by G2 followed by G4 as little variation had been observed from 41.8 to 45.9 q/ha among genotypes.

Ranking of wheat genotypes as per AMMI based measures and yield

Stability alone is not a desirable selection criterion as stable genotypes may not be a high yielders, simultaneous use of yield and stability in a single measure is essential (Kang, 1993; Farshadfar, 2008). Simultaneous Selection Index also referred to as genotype stability index (GSI) or yield stability index (YSI) (Farshadfar *et al.,* 2011) was computed by adding the ranks of stability measure and average yield of genotypes.

As per the least values of simultaneous ranks for IPCA1 measure HI 1633 and Raj 4083 were considered as stable with high yield, whereas high values suggested as least stable yield for HD 2932 genotype (Table 4). EV measure identified HI 1633 and Raj 4083 by whereas SPIC favoured HI 1633 and HD 3090 genotypes. Genotypes HI 1633 and Raj 4083 possessed lower value of Za measure. WAASB measure observed suitability of GW 509 and HI 1633 genotypes. Superiority index while weighting 0.65 and 0.35 for yield and stability found HI 1633 and Raj 4083 as of stable performance with high yield. Composite measures

MASV as well as MASV1 selected HI 1633, GW 509 genotypes of choice for these locations of the zone. Values of least magnitude of ASV and ASV1 pointed towards HI 1633 and Raj 4083 wheat genotypes (Oyekunle *et al.,* 2017). In the present study, all measures identified genotypes HI 1633 and Raj 4083 as stable and high yielders. PRVG and MHPRVG measures observed suitability of HI 1633 and Raj 4083 wheat genotypes. More over the average yield of genotypes ranked HI 1633 and Raj 4083 as of order of choice.

Biplot graphical analysis

Loadings of stability measures as per first two significant principal components for evaluated wheat genotypes were reflected in Table 5. Biplot graphical analysis based on two significant principal component analysis (PCA) as these PCAs accounted for 88.5% of variation of the original variables (Balestre *et al.,* 2009). Considered stability measures of wheat genotypes grouped into two major groups (Fig 1). Larger group comprised of SI, ASTAB, SIPC, Za, ASV, MASV1 measures. Yield clubbed with PRVG and MHPRVG measures in separate group. EV joined with ASV and IPCA1 measures. Stability measure WAASB maintained distance from other stability measures and observed as outliers in biplot graphical analysis.

Association analysis

Correlation values were computed for each pair of measures to have an idea about linear association analysis among stability measures. Mean yield showed highly significant positive correlations with SI, MHPRVG and PRVG values (Table 6). While SI expressed only negative values with measures and exceptional positive behaviour with yield, MHPRVG and PRVG. Measure WAASB exhibited direct relationships with other measures except of moderate negative with yield, SI, MHPRVG and PRVG. AMMI based measures Za, SIPC, SV, ASV1, MASV1, MASV and ASTAB exhibited only positive correlation values among themselves and with others (Ajay *et al*., 2019). Only indirect relations were observed with stability measures SI, PRVG, MHPRVG and yield. Similar behaviour of negative correlations had displayed by IPCA1, ASV1, MASV1, ASV and Za. At the same time positive correlations were expressed by MASV, SIPC, EV also.

Table 6: Association analysis of SI with other stability measures (2018-19).

Measure	MASV1	MASV	ASV1	ASV	Za	EV	SIPC	ASTAB	WAASB	SI	MHPRVG	PRVG	Yield
IPCA1	0.798	0.742	0.993	0.972	0.899	0.397	0.687	0.886	0.940	-0.602	-0.357	-0.239	-0.231
MASV1		0.988	0.856	0.898	0.971	0.751	0.939	0.927	0.950	-0.497	-0.173	-0.068	-0.100
MASV			0.804	0.847	0.956	0.837	0.963	0.929	0.924	-0.390	-0.059	0.045	0.015
ASV1				0.993	0.934	0.453	0.740	0.920	0.969	-0.632	-0.366	-0.248	-0.252
ASV					0.952	0.489	0.775	0.935	0.980	-0.657	-0.376	-0.260	-0.276
Za						0.723	0.929	0.971	0.993	-0.534	-0.228	-0.112	-0.121
EV							0.899	0.730	0.648	-0.001	0.260	0.338	0.338
SIPC								0.877	0.880	-0.381	-0.094	0.005	0.004
ASTAB									0.971	-0.445	-0.127	-0.007	-0.026
WAASB										-0.568	-0.267	-0.148	-0.158
SI											0.936	0.891	0.903
MHPRVG												0.992	0.983
PRVG													0.991

Table 7: Parentage details of genotypes and environmental conditions (2019-20).

Code	Genotype	Parentage	Environments	Latitude	Longitude	Altitude
G1	GW519	(GW394/PBW519//AKAW4627)	Niphad	20°4′N	74°6′E	551 m
G2	HI1646	(DANPHE/3/PBW343*2/KUKUNA //PBW343*2/KUKUNA)	Pravaranagar	14°71′N	76°17′E	
G3	HD3090	(SFW/VAISHALI//UP2425)	Pune	18°31′N	73°51′E	562 m
G4	RAJ4083	(PBW 343/UP 2442//WR 258/UP 2425)	Akola	20°42′N	77°0′E	292 m
G5	UAS3008	(HI977/PBW343/DBW14)	Parbhani	19°15′N	76°46′E	413 m
G6	MACS6749	(MACS6221/Raj4037)	Nashik	19°59′N	73°47′E	583 m
G7	HD2932	(KAUZ/STAR//HD2643)	Karad	17°17′N	74°10′E	577
G8	HI1641	(HI1544/RAJ3777)	Kolhapur	16°41′N	74°14′E	578
G9	HI1642	(CAPAN4068/MACS2496)	Dharwad	15°27′N	75°0′E	724 m
G10	HI1633	(GW322/PBW498)	Arbhavi	15°84′N	74°51′E	625m
G11	MACS6752	(PBW553/RAJ4083)	Mudhol	16°19′N	75°17′E	546 m
			Nippani	16°23′N	74°22′E	606 m
			Ugar-Khurd	16°39′N	74°49′E	548 m

Second year of study (2019-20)

AMMI analysis of genotypes

AMMI analysis observed highly significant effects of environment (E), G×E interaction and genotypes (G). Environment explained about significantly 59.5% of the total sum of squares due to treatments indicating that diverse environments caused most of the variations in genotypes yield (Table 8). Significant proportion of G×E interaction deserves the stability estimation of genotypes over environments (Veenstra *et al.,* 2019). Genotypes explained only 1.6% of total sum of squares, whereas G×E interaction accounted for 14.7% of treatment variations in yield. More of G×E interaction sum of squares as compared to genotypes indicated the presence of genotypic differences across environments and complex G×E interaction for wheat yield. Further partitioning of G×E interaction through the AMMI model revealed that the first seven multiplicative terms (IPCA1, IPCA2, IPCA3, IPCA4, IPCA5, IPCA6 and IPCA7) explained 31.5%, 27.2%, 12.9%, 9.3%, 7.8%, 4.6% and 3.5% of interaction sum of squares, respectively. Total of significant components were 97.1% and remaining 2.9% was noise, thus discarded (Adjebeng *et al*., 2017).

Stability analysis

Least value of absolute IPCA1 expressed by G3, G10, G1 and higher value achieved by G4 (Table 9). Low values of (EV) associated with stable genotype accordingly, the genotype G10 followed by G8, G4 and genotype G3 had the maximum value of EV measure. The lower value SIPC measure identified G10 followed by G8, G4 as the most stable genotypes, whereas G9 would be of least stable behaviour. Za measure considered absolute value of the relative contribution of IPCs to the interaction revealed G5 and G3 G1 genotypes as most stable in descending order of stability, whereas G10 genotype with the least stability. ASTAB measure observed genotypes G10 and G8 G2 as most stable and genotype G7 was least stable in this study (Rao and Prabhakaran, 2005). ASV measure showed that genotypes G10, G2, G1 possessed lower values would express stable performance and G7 be of least stable type. Values of ASV1 selected G10, G1, G2 for their stable

Table 8: AMMI analysis of wheat genotypes evaluated under MET (2019-20).

Source	Degree of freedom	Mean sum of squares	Proportional contribution of factors	G×E interaction sum of squares (%)	Cumulative sum of squares (%) by IPCA's
Treatments	142	235.95	75.82		
Genotype (G)	10	71.24	1.61		
Environment (E)	12	2191.27	59.50		
GxE interaction	120	54.15	14.70		
IPC1	21	97.64		31.56	31.56
IPC2	19	93.12		27.23	58.79
IPC3	17	49.53		12.96	71.75
IPC4	15	40.37		9.32	81.07
IPC5	13	39.29		7.86	88.93
IPC6	11	27.30		4.62	93.55
IPC7	9	25.36		3.51	97.06
Residual	15	12.72			
Error	429	24.91			
Total	571	77.39			

Table 9: Measures of stability as per AMMI analysis of wheat genotypes (2019-20).

Genotype	IPCA1	MASV1	MASV	ASV1	ASV	Za	EV	SIPC	ASTAB	WAASB	SI	MHPRVG	PRVG	Yield
G1	0.19	5.14	4.58	0.89	0.88	11.44	0.053	6.86	46.66	0.890	51.36	0.979	0.993	37.00
G2	0.55	3.50	3.32	0.94	0.85	23.93	0.055	6.26	34.90	0.750	57.04	0.998	1.003	37.07
G3	0.11	5.59	5.24	2.37	2.37	5.89	0.062	7.32	69.88	1.122	59.35	1.009	1.021	37.98
G4	1.91	4.35	3.74	2.78	2.40	20.84	0.029	5.62	44.24	1.042	11.96	0.936	0.944	34.80
G5	0.57	5.19	4.85	2.03	1.98	0.00	0.055	7.28	58.16	1.131	25.74	0.954	0.968	35.86
G6	0.95	4.97	4.38	1.90	1.77	89.04	0.054	7.17	50.53	1.096	47.38	0.991	1.000	37.16
G7	3.27	5.34	4.60	4.59	3.91	75.03	0.054	7.25	88.08	1.354	27.00	0.964	0.984	36.40
G8	1.78	2.86	2.50	2.47	2.10	112.24	0.022	4.07	27.54	0.669	81.92	1.030	1.034	38.49
G9	1.70	5.07	4.65	3.25	3.00	104.23	0.052	8.13	68.89	1.413	32.62	0.981	0.994	36.88
G10	0.12	1.46	1.37	0.62	0.61	113.11	0.006	2.23	5.37	0.328	78.30	1.010	1.011	37.56
G11	0.80	4.81	4.38	1.96	1.87	109.56	0.059	7.94	52.84	1.156	73.28	1.040	1.048	38.94

Table 10: Simultaneous ranks of wheat genotypes as per yield and AMMI based measures (2019-20).

Genotype	IPCA1	MASV1	MASV	ASV1	ASV	Za	EV	SIPC	ASTAB	WAASB	SI	MHPRVG	PRVG	Yield
GW519	10	15	14	9	10	10	12	12	12	4	6	8	8	7
HI1646	10	9	9	9	8	11	15	10	9	3	5	5	5	6
HD3090	4	14	14	10	11	5	14	12	13	7	4	4	3	3
RAJ4083	21	15	15	20	20	15	14	14	15	5	11	11	11	11
UAS3008	15	19	20	16	16	11	18	18	18	8	10	10	10	10
MACS6749	12	11	10	9	9	12	11	11	11	6	7	6	6	5
HD2932	20	19	17	20	20	15	16	16	20	10	9	9	9	9
HI1641	11	4	4	10	9	12	4	4	4	2	1	2	2	2
HI1642	16	15	17	18	18	16	12	19	17	11	8	7	7	8
HI1633	6	5	5	5	5	15	5	5	5	1	2	3	4	4
MACS6752	7	6	7	6	6	10	11	11	8	9	3	1	1	1

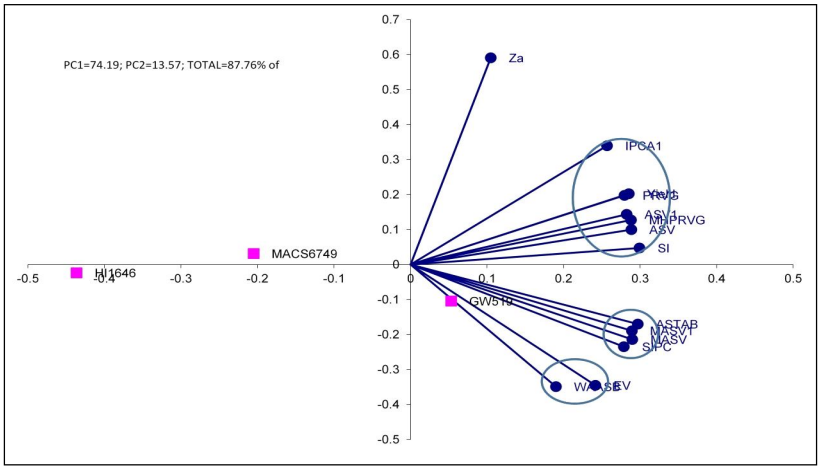

Fig 2: Biplot graphical analysis of stability measures for wheat genotypes evaluated under MET (2019-20).

Table 11: Loadings of stability measures as per first two PC's 19-20.

Measure	PC1	PC2
IPCA1	0.257	0.340
MASV1	0.289	-0.189
MASV	0.290	-0.214
ASV1	0.282	0.143
ASV	0.289	0.100
Za	0.105	0.591
EV	0.242	-0.345
SIPC	0.279	-0.235
ASTAB	0.297	-0.170
WAASB	0.190	-0.349
SI	0.299	0.047
MHPRVG	0.288	0.127
PRVG	0.280	0.198
Yield	0.285	0.203
% variance	74.19	13.57

behaviour whereas G7 would express unstable performance. Measures MASV and MASV1 consider all significant IPCAs. Values of MASV and MASV1 measures settled for the genotypes, G10, G8, G2 for their stable yield performance (Ajay *et al.,* 2019). The lower values of WAASB associated with stable nature of genotypes as G10, G8, G1 for considered locations of the zone at the same time maximum value obtained by G9, that is, the one that deviates maximum from the average performance across environments. Lower value of Superiority index pointed towards G4, G5 and G7 whereas large value by G8. Genotypes G4, G5 and G7 were identified for their more stable yield performance by MHPRVG and PRVG measure along with least stable yield of G11. Maximum yield expressed by G11 followed by G8 and G3 as little variation had been observed from 34.8 to 38.5 q/ha among genotypes.

Ranking of wheat genotypes as per AMMI based measures and yield

HD3090, HI1633 and MACS6752 expressed lower values for IPCA1 measure for stable with high yield, whereas high values suggested least stable yield for RAJ4083 genotype (Table 10). EV along with SPIC measure settled for HI1641, HI1633 and MACS6752 genotypes. HD3090, GW519 and MACS6752 genotypes possessed lower value of Za measure. WAASB measure observed suitability of HI1633, HI1641 and HI1646 genotypes. Superiority index while weighting 0.65 and 0.35 for yield and stability found HI1641, HI1633 and MACS6752 as of stable performance with high yield. Analytic measures MASV as well as MASV1 selected HI1641, HI1633, MACS6752 genotypes of choice for these

Table 12: Association analysis of SI with other stability measures (2019-20).

Measure	MASV1	MASV	ASV1	ASV	Za	EV	SIPC	ASTAB	WAASB	SI	MHPRVG	PRVG	Yield
IPCA1	0.180	0.091	0.880	0.820	0.301	-0.040	0.140	0.472	0.473	-0.463	-0.345	-0.296	-0.321
MASV1		0.992	0.485	0.548	-0.443	0.869	0.929	0.899	0.895	-0.572	-0.368	-0.240	-0.226
MASV			0.426	0.499	-0.475	0.899	0.940	0.882	0.875	-0.533	-0.327	-0.201	-0.188
ASV1				0.993	0.145	0.228	0.405	0.761	0.734	-0.530	-0.336	-0.245	-0.262
ASV					0.113	0.293	0.469	0.807	0.783	-0.534	-0.323	-0.225	-0.239
Za						-0.408	-0.287	-0.244	-0.137	0.475	0.554	0.534	0.524
EV							0.941	0.767	0.741	-0.300	-0.082	0.034	0.032
SIPC								0.844	0.899	-0.463	-0.203	-0.084	-0.085
ASTAB									0.938	-0.581	-0.351	-0.211	-0.213
WAASB										-0.643	-0.371	-0.252	-0.256
SI											0.941	0.901	0.905
MHPRVG												0.987	0.982
PRVG													0.997

locations of the zone. Values of least magnitude of ASV and ASV1 pointed towards HI1633, MACS6752 and HI1646 wheat genotypes (Oyekunle *et al.,* 2017). PRVG measure found MACS6752 and HI1641 HD3090 while values of MHPRVG measure preferred MACS6752, HI1641 and HI1633 wheat genotypes. More over the average yield of genotypes ranked MACS6752, HI1641 and HD3090 as of order of choice. In the present study, all measures identified genotypes HI1633, MACS6752 and HI1646 as stable and high yielders.

Biplot graphical analysis

Graphical analysis considered first two significant principal component analysis (PCA) as these PCAs explained more than 87.8% of variation of the original variables (Balestre *et al.,* 2009). The loadings of stability measures for evaluated wheat genotypes were reflected in Table 11. The stability measures of wheat genotypes grouped into four major groups (Fig 2). WAASB measure grouped with EV in separate cluster. Nearby cluster comprised of ASTAB, MASV, MASV1, SIPC measures. Distant cluster of SI with yield ASV, IPCA1, ASV1, PRVG and MHPRVG measures. Measure Za maintained distance from other stability measures and observed as outlier in graphical analysis.

Association analysis

Average yield of genotypes showed significant positive correlations with SI, MHPRVG, PRVG and Za (Table 12). Similar pattern were also expressed by PRVG and MHPRVG analytic measures. SI expressed only negative values of correlation with other stability measures (IPCA1, ASV1, MASV1, ASV, WAASB) except with yield, MHPRVG and PRVG values. WAASB measure exhibited only indirect relationships with SI, MHPRVG, PRVG and yield otherwise direct relations observed with remaining measures. AMMI based measures Za, SIPC, SV, ASV1, MASV1, MASV and ASTAB achieved only positive correlation values among themselves and with others (Ajay *et al.,* 2019). ASTAB had indirect relation with SI, PRVG, MHPRVG and yield. Same behaviour of negative correlations had displayed by IPCA1, ASV1, MASV1, ASV, MASV also. Measures Za and EV maintained positive values of correlation with yield, MHPRVG and PRVG.

CONCLUSION

AMMI model is an effective tool to study GxE interaction in multi-environment yield trials. Stability measures by simultaneous use of AMMI model and yield would be more meaning full and useful as compared to measures consider either the AMMI or yield of genotypes only. The stability measures found to be correlated well with each other. Measures MASV, MASV1, WAAB and SI could be used to identify stable high-yielding genotypes as these measures selected HI1633, Raj4083 for first year while HI1641 and MACS6752 for the second year.

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Conflict of interest

All authors declare that they have no conflict of interest.

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